

Mars Global Reference Atmospheric Model (Mars-GRAM) Version 3.8: Users Guide

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PREFACE

These improvements to the NASA/MSFC Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.8) were sponsored by the NASA Marshall Space Flight Center through the Electromagnetics and Aerospace Environments Branch, Systems Engineering Division of the Systems Analysis and Integration Laboratory.

For those unfamiliar with earlier versions of Mars-GRAM, NASA Technical memorandum 108509 "Mars Global Reference Atmospheric Model (Mars-GRAM 3.34) Programmer's Guide", and NASA TM 108513 "A Revised Thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.4)" are recommended. These reports are available electronically from the NASA Technical Report Server at Internet address.

<http://techreports.larc.nasa.gov/cgi-bin/NTRS>

For information on obtaining Mars-GRAM Version 3.8 code and data, as well as additional copies of this report, contact

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Mars Global Reference Atmospheric Model (Mars-GRAM) Version 3.8: Users Guide

1. Introduction

The Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering-oriented model of the atmosphere of Mars, based on data observed by the Mariner and Viking missions. Versions up to and including 3.34 were documented by Justus (1991) and Justus, James and Johnson (1996). Version 3.4 was discussed by Justus, Johnson, and James (1996). Readers unfamiliar with earlier versions of Mars-GRAM are urged to read these reports to familiarize themselves with the scope, capabilities, functionality, and terminology of the program. Changes made for versions 3.5, 3.6, and 3.7 are summarized in Appendix F.

Section 2 of this report describes changes made for Mars-GRAM Version 3.8. Section 3 explains how to run Mars-GRAM. Sample results are presented in Section 4. Sample input and output from version 3.8 with descriptive details are presented in Appendices A through E.

2. Changes Made in Mars-GRAM Version 3.8

The following is a summary of new features and changes in Mars-GRAM Version 3.8. A synopsis of changes in versions 3.5 through 3.7 is given in Appendix F. Code line numbers (in parentheses) give approximate starting line number(s) where changes appear in the Mars-GRAM code.

- Changed former batch version main program code line numbers from "MARB" to "MGRM" (MGRM 1)
- Reduced the number of graphics output files and included more variables in each file (SETU 36, SETU 90, DSTP 280) See header descriptions for the new graphics output files in Appendix A.
- Changed to NASA Ames Mars Global Circulation Model (MGCM) low resolution topography (SETU 15) (Figure 4.1) Topographic height at the poles was corrected to apply at all longitudes.
- Decreased temperature gradient at polar cap edge (ALBL 26, TSRF 53a) This has the effect of reducing the magnitude of thermal winds aloft.
- Revised procedure whereby input heights ≤ -5 km are treated as being at the topographic surface (ATM2 54b, ATM2 82, DSTF 14)

- Revised lapse rate at surface for surface temperature calculation (ATM2 67, ATM2 99)
- Revised perturbation magnitudes versus height (ATM2 217b, DSTP 50a, DSTP 199b)
- Introduced a new iterative procedure for finding ZF (height of 1.26 nbar level) for the hydrostatic interpolation option (ATM2 2144a)
- Added pressure scale height to DATASTEP output (DSTP 2a)
- Added corlim factor (ratio of trajectory step size to minimum size for assured perturbation accuracy) with warning messages if corlim < 1 (DSTP 80)
- Added gradient wind (curvature) correction to winds (DSTP 160g)
- Added check to limit wind components to less than sound speed divided by square root of two (DSTP 151a, DSTP 160h)
- Treated "surface" winds as being at 10 cm, rather than Viking level of 1.6 m (DSTP165)
- Added new wind perturbation model, including tidal winds (DSTP 229, DSTP 244c, WAVE 91, MGRM 88)
- Included computation of F1 ionization peak altitude and molecular weight. F1 peak height has also been added to output files (DSTP 246i, DSTP 290, DSTP 254d, STRA 47a)
- Added climate factors to LIST output (DSTP 256a)
- Converted surface pressure latitude variation to cosine terms, to insure diurnal amplitude goes to zero at the poles (PSRF 61)
- Changed to new values of reference ellipsoid radii, gravity term, and rotation rate (consistent with current JPL values) (RLPS 9a, RLPS 18a)
- Added centrifugal term to gravity (RLPS 22)
- Used molecular scale temperature in stratospheric interpolation to account for height variation of molecular weight (STRA 16, STRA 47h)
- Removed ES(8) and ES(9) terms from calculation of ZF, but not TF. This makes perturbation standard deviations more consistent in the thermosphere (STW2 37d)

- Included effect of height change of molecular weight in computation of density scale height (STW2 61a, THRM 133b)
- Added Pathfinder landing site to set of locations that have terrain height specified (TERN 12a)
- Applied climate factors to minimum, maximum, and average surface temperatures (TMPS 138e)
- Included $\text{Cos}(\text{LAT})/\text{Cos}(75)$ factor in wave perturbations to insure zero amplitude at the poles (WAVE 77a)
- Allowed variable climate factors to be passed from trajectory program to Mars-GRAM subroutines (CFIN 1, MART 58b)
- Allowed optional high resolution solar positions to be passed from trajectory program to Mars-GRAM subroutines (DUMT 35a, MGRM 72, DSTP 35)
- Added subroutine SublTchk to assure that temperatures do not go below CO₂ sublimation temperature (ATM2 72d, ATM2 106b, PRES 29a, STCK 1, STRA 47k, THRM 132b)

3. How to Run Mars-GRAM

How to Obtain the Program

All source code and required data files are available from a file transfer protocol (ftp) server at NASA Marshall Space Flight Center. The ftp site also contains example input and output files and "readme" files. To obtain the program source code and data files by ftp, see contact information in the preface. See Appendix D for a summary of the program and data files available on the ftp site.

Running the Program

There are two ways to run Mars-GRAM: (1) as a subroutine in a (user-provided) main driver program (such as a trajectory program) and (2) as a stand alone program, using a NAMELIST format input file, in which values for all input options are provided. To use Mars-GRAM 3.8 as a subroutine, see discussion in Appendix E and use example file dummytraj.f (available in the ftp file distribution) as a guide. File README2.txt (available in

the ftp file distribution) also discusses use of dumytraj.f as an example for using Mars-GRAM as a subroutine.

The steps involved in setting up and running Mars-GRAM in stand alone mode are the following:

- (1) Compile and link the three FORTRAN source code files marsgram.f, marssubs.f, and setup.f into an executable program (assumed to be called marsgram)
- (2) Make sure that necessary data files ARCHGTS.DAT (topographic height information) and COSPAR.DAT (COSPAR model atmosphere data) are in the same file directory as the executable program
- (3) Prepare a NAMELIST format input file (called INPUT) with the desired values of all input options. See example in Appendix B.
- (4) If trajectory input mode (rather than automatic profile mode) is desired, prepare a trajectory input file (called TRAJDATA) containing time, height, latitude, longitude, and climate factor values (further discussion below).
- (5) Run the program by entering its executable name (e.g., marsgram). The program automatically opens and reads the INPUT file (and the TRAJDATA file, if trajectory mode is used) and the data files ARCHGTS.DAT and COSPAR.DAT.

If the program is run in profile mode, the user inputs values of fixed increments of time, height, latitude, and longitude. In this mode, the program automatically increments the position until the desired number of positions (NPOS) are evaluated. In trajectory mode, Mars-GRAM reads time and position information from the TRAJDATA file. Two auxiliary programs are provided on the ftp server for building or modifying trajectory files. Program rdmt.f is a FORTRAN program to read a trajectory file that contains one value of time, height, latitude, and longitude per line. The program adds climate factors to each line. Program bldmt.f builds a trajectory file that consists of fixed steps in height, latitude, longitude, or time. Program bldmt.f provides a means for generating "trajectory" positions on a height-latitude cross section or a latitude-longitude map, for example. See discussion in comment lines of these two programs for details about their use.

Program Input

Appendix B gives a sample of the NAMELIST file INPUT for Mars-GRAM 3.8. Whether the subroutine or stand alone version is used, the input variables whose values must be supplied in the INPUT file are as follows:

LSTFL	name of the LIST file (see example LIST file in Appendix C). For a listing to the console in the stand alone version enter the filename CON.
-------	--

OUTFL	name of the OUTPUT file (see discussion of this file in Appendix A).
MONTH	month (1 through 12) for the initial time
MDAY	day of the month for the initial time
MYEAR	year for the starting time, a 4-digit number Alternately the years 1970-2069 can be input as a 2-digit number
NPOS	maximum number of positions to evaluate, if an automatically-generated profile is to be produced. Use 0 if the trajectory positions are to be read in from a TRAJDATA file.
IHR	initial time, hour of the day GMT
IMIN	initial time, minute of the hour
SEC	initial time, seconds of the minute
ALS0	value of the areocentric longitude of the Sun (Ls, in degrees) at which a dust storm is to start Use a value of 0 if no dust storm is to be simulated. Dust storm can be simulated only during the season of the Mars year for which Ls is between 180 and 320 degrees.
INTENS	dust storm intensity, an arbitrary intensity scale, with allowable values ranging from 0.0 (no dust storm) to 3.0 (maximum intensity dust storm)
RADMAX	maximum radius (km) a dust storm can attain, developing according to the parameterized space and time profile of build-up and decay in the program If a value of 0 or more than 10 000 km is used, the storm is taken to be of global dimensions (uniformly covering the planet), but still assumed to build up and decay in intensity according to the same temporal profile.
DUSTLAT	latitude (degrees, North positive) for the center of the dust storm.
DUSTLON	longitude (degrees, West positive) for the center of the dust storm.
F107	the 10.7 cm solar flux in its usual units of 10^{-22} W/cm ² at the average Earth orbit position (1 AU) The solar flux is automatically converted by the program to its value at the position of Mars in its orbit.
STDL	standard deviation parameter for short-term variations in the Stewart model thermosphere The normal value is 0; the allowable range is from -3.0 to +3.0.

MODPERT	model number for the perturbations to be computed: 1 is for the random (mountain wave) model , 2 is for the Zurek (tidal) wave model, and 3 means to use combined perturbations from both models.
NR1	seed value (integer) for the random number generator The allowable range is 1 to 29999. To do Monte-Carlo simulations with a variety of perturbations, use a different random number seed on each model run. To repeat a given perturbation sequence on a later model run, use the same random number seed value.
NVARX	x-code for the plotable output (x-y pairs for 1-D line graphs or x-y-z triplets for 2-D contour plots) See Appendix A for a list of the variables associated with the x code (e.g., if NVARX = 1, output is for plotting versus the height above the reference ellipsoid).
NVARY	y-code for 2-D contour plot output (x-y-z triplets) Use a y-code value of 0 for 1-D line graph (x-y pair) plots. See Appendix A for a list of y-code values and parameters represented.
LOGSCALE	parameter to control the units of the output values of density and pressure on the output plot files A value of 0 means use regular density and pressure units (kg/m^3 and N/m^2); 1 means to output the logarithm (base-10) of the regular units; and 2 means to output the percentage deviation from the COSPAR values of density and pressure.
FLAT	latitude of the initial point to simulate (degrees, North positive)
FLON	longitude of the initial point to simulate (degrees, West positive)
FHGT	height (km) of the initial point to simulate above the reference ellipsoid
DELHGT	height increment (km) between successive steps in an automatically generated profile (positive upward)
DELLAT	latitude increment (degrees, Northward positive) between successive steps in an automatically generated profile
DELLON	longitude increment (degrees, Westward positive) between successive steps in an automatically generated profile
DELTIME	time increment (seconds) between steps in an automatically generated profile
CF0	climate adjustment factor at the surface (multiplier to be used to increase or decrease the nominal Mars-GRAM surface temperature, nominal = 1)

CF5	climate adjustment factor at 5-km altitude (multiplier to be used to increase or decrease the nominal Mars-GRAM temperature at 5-km significant level, nominal = 1)
CF15	climate adjustment factor at 15-km altitude (multiplier to be used to increase or decrease the nominal Mars-GRAM temperature at 15-km significant level, nominal = 1)
CF30	climate adjustment factor at 30-km altitude (multiplier to be used to increase or decrease the nominal Mars-GRAM temperature at 30-km significant level, nominal = 1)
CF50	climate adjustment factor at 50-km altitude (multiplier to be used to increase or decrease the nominal Mars-GRAM temperature at 50-km significant level, nominal = 1)
CF75	climate adjustment factor at 75-km altitude (multiplier to be used to increase or decrease the nominal Mars-GRAM temperature at 75-km significant level, nominal = 1)
deltaZF	additive adjustment to modify the height (km) of the 1.26-nbar pressure level (ZF altitude), nominal = 0
deltaTF	additive adjustment to modify the temperature (K) at the ZF altitude, nominal = 0
deltaTEX	additive adjustment to modify the temperature (K) of the exosphere (asymptotic temperature approached at very high altitudes), nominal = 0
CFp	climate adjustment factor for surface pressure (multiplier to be used to increase or decrease the nominal Mars-GRAM surface pressure value, nominal = 1)
ipopt	option for interpolating between 75-km significant level and altitude of 1.26-nbar level (height ZF): 0 means use regression to set ZF and use non-hydrostatic interpolation, 1 means use hydrostatic interpolation between 75 km and ZF height (with ZF height determined by the hydrostatics of the temperature profile)
rpscale	multiplicative factor for density and wind perturbations (1 = nominal)
NMONTE	number of Monte Carlo runs during one execution of the program. New/different starting random numbers are automatically generated for each of the Monte Carlo profiles (or trajectories)

iup option controlling output of LIST file and graphics output files (0 = none, other than 0 (default) indicates generate these files)

Two auxiliary input files are required. The file ARCHGTS.DAT contains the topographic height data array (topographic height, km, above the reference ellipsoid). The file COSPAR.DAT contains the height profile of COSPAR temperature, density, and pressure values.

If the (pre-computed) trajectory mode is used (NPOS=0), trajectory data must be read from the TRAJDATA file. Each line of the TRAJDATA file is a position and time for which to compute atmospheric parameters. The input lines contain time (seconds, from the initial time), height (km, relative to the reference ellipsoid), latitude (degrees, North positive), and longitude (degrees, West positive). Each line of the TRAJDATA file must also contain climate factors (CF0 - CF75, deltaZF, deltaTF, deltaTEX, and CFp; see above definitions). Programs rdmgt.f and bldmgt.f (provided on the ftp file server) assist the user in building a trajectory file and adding climate factor values. See comments embedded in the source code of these programs for details.

For automatically-generated profiles, output is generated until the maximum number of positions (NPOS) is reached. For trajectory positions read in from the TRAJDATA file, output is generated until the end of the file is reached.

Program Output

There are three general types of program output (1) a "LIST" file containing header and descriptor information, suitable for printing or viewing by an analyst (example LIST file in Appendix C), (2) an "OUTPUT" file containing one header line and one line per output position, suitable for reading into another program for additional analysis (example OUTPUT file in Appendix A), and (3) a set of "plotable" output files, or graphics output files, i.e., text files suitable for input to a graphics program (descriptions in Appendix A).

The graphics output files contain either x-y data pairs or x-y-z data triplets, determined by the selected values for the x-code (NVARX) and y-code (NVARY). If 1-D line-graph (x-y pair) data is the selected plot output option then y-code = 0 is input. If 2-D contour plot (x-y-z triplet) data is the selected plot output option, then a non-zero value of y-code is input. See the list of codes for x-code and y-code below.

If the user desires to suppress the LIST, OUTPUT and graphics output files (so that output can be handled in a user-provided program), this is done by setting the LIST file unit number (iup) to 0 in the NAMELIST format INPUT file. The unit number associated with the "screen" output (iu0), normally 6 in the stand alone version, can be set to any other value, by changing it at program code line BLKD 16, and re-compiling the program.

4. Sample Results

Earlier versions of Mars-GRAM used topographic height data manually read from U.S. Geological Survey maps of Mars surface topography. With version 3.8, the low resolution topography used by the NASA Ames Mars Global Circulation Model (MGCM) is employed. Data at each pole was averaged over longitude, so that a common polar value for each pole would be approached regardless of which longitude a trajectory is approaching a given pole. Figure 4.1 shows contours of the Ames MGCM topography at 1 km contour intervals. Although this figure displays East longitude, Mars-GRAM continues to use West longitude for its input and output.

Figure 4.2 shows a height-latitude cross section of temperature for northern winter solstice ($L_s = 270$ degrees) at noon local solar time. Altitude is height above local topographic surface. Despite the several changes and improvements noted in Section 2, this cross section is still similar to one from earlier versions of Mars-GRAM (compare Figure 11 in Appendix B of Justus, James, and Johnson, 1996).

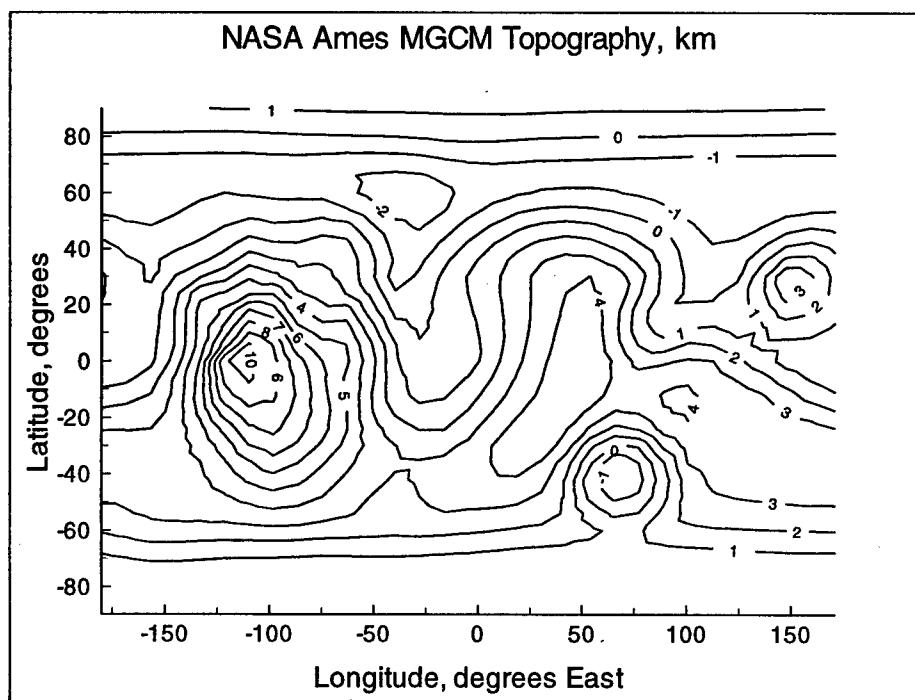


Figure 4.1 Contours of topographic altitude (km) from the NASA Ames MGCM low resolution data

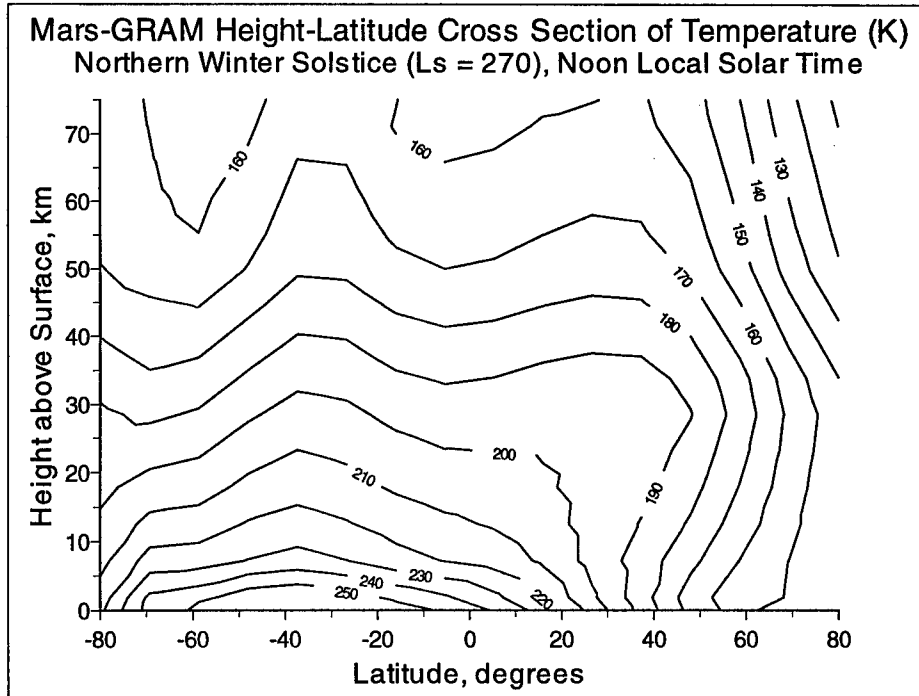


Figure 4.2 Mars-GRAM Version 3.8 height-latitude cross section of temperature at Northern winter solstice ($L_s = 270$ degrees) at noon local solar time.

5. References

1. Justus, C.G. (1991): "Mars Global Reference Atmospheric Model for Mission Planning and Analysis", *J. Spacecraft and Rockets*, 28(2), 216-221.
2. Justus, C.G., B.F. James, and D.L. Johnson (1996): "Mars Global Reference Atmospheric Model (Mars-GRAM 3.34): Programmer's Guide", NASA Technical Memorandum 108509.
3. Justus, C.G., D.L. Johnson, and B.F. James (1996): "A Revised Thermosphere for the Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.4)", NASA Technical Memorandum 108513.

Appendix A

Headers for New Version 3.8 Output Files

Earlier versions of Mars-GRAM graphics output files had single model output variables in the format of

Var_X Variable

or

Var_X Var_Y Variable

These files are read into a graphics program to produce 2-dimensional (Variable versus Var_X) or 3-dimensional (Variable versus Var_X and Var_Y) graphs.

For Mars-GRAM 3.8 several output variables were combined into fewer graphics output files, since most plotting programs now allow the user to select from among several data items per line for plotting. To aid in interpretation, the new graphics output files now contain header information describing the output variables. New graphics outputs files and headers for Mars-GRAM 3.8 are

File = OUTPUT (or other name, as prescribed in the NAMELIST INPUT file)

Time = time after initial input time (sec)
Height = altitude above reference ellipsoid (km)
Lat = latitude (degrees, North positive)
LonW = longitude (degrees, West positive)
DensAV = average density (kg/m**3)
Temp = average temperature (K)
EWind = eastward wind component (m/s, positive toward East)
NWind = northward wind component (m/s, positive toward North)
sigD = standard deviation for density perturbations (% of mean)
sigwa = standard deviation of density wave perturbations (% of mean)
Ls = areocentric longitude of Sun from Mars (degrees)

File = Density.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVAR_Y value)
DENSLO = low (~ mean - 1 standard deviation) density (kg/m**3)
DENSAB = average (mean) density (kg/m**3)
DENSBI = high (~ mean + 1 standard deviation) density (kg/m**3)
DENSOT = total (mean plus perturbed) density (kg/m**3)

File = Perturb.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
SigD = standard deviation of density perturbations (% of mean)
DensP = density perturbation value (% of mean)
corlim = fraction of minimum step size for accuracy of perturbations
(should be > 1 for insured accuracy of perturbations)
SigU = standard deviation of wind perturbations (m/s)
DensWA = density perturbation amplitude from wave model (% of mean)
AmpWind = wind perturbation amplitude from wave model (m/s)

File = Surftemp.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
Tmin = daily minimum surface temperature for this lat-lon (K)
Tavg = daily average surface temperature for this lat-lon (K)
Tmax = daily maximum surface temperature for this lat-lon (K)
TminC = daily minimum surface temperature for this lat-lon (degrees C)
TavgC = daily average surface temperature for this lat-lon (degrees C)
TmaxC = daily maximum surface temperature for this lat-lon (degrees C)

File = Thrmdata.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
Tbase = temperature at 1.26 nbar level (K)
Zbase = altitude of 1.26 nbar level (km)
F1peak = altitude of F1 ionization peak (km)
MolWgt = mean molecular weight (kg/kg.mole)

File = Tpresght.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
Temp = mean temperature (K)
Pres = mean pressure (N/m**2)
TdegC = mean temperature (degrees C)
Pres_mb = mean pressure (mb)

Hrho = density scale height (km)
Psurf = surface pressure for this lat-lon-time (mb)

File = Winds.txt

Var_X = user-selected plot variable (determined by NVARX value)
Var_Y = (Optional) user-selected plot variable (from NVARY value)
EWmean = mean eastward wind component (m/s, positive toward East)
EWpert = eastward wind perturbation (m/s)
EWtot = total (mean plus perturbed) eastward wind (m/s)
NSmean = mean northward wind component (m/s, positive toward North)
NSpert = northward wind perturbation (m/s)
NSTot = total (mean plus perturbed) northward wind (m/s)

Model input codes used to select the plotable x and y parameters (Var_X and Var_Y) are as follows:

Code	Parameter
1	Height (above reference ellipsoid, km)
2	Height (above local terrain, km)
3	Latitude (deg.)
4	West Longitude (deg.)
5	Time from start (Earth seconds)
6	Time from start (Martian Sols)
7	Areocentric Longitude of Sun, Ls (deg.)
8	Local Solar Time (Mars hours = 1/24 Sols)
9	Pressure (mb)

Appendix B

Example NAMELIST Format Input File

The following is an example of the NAMELIST format input file required by Mars-GRAM 3.8. Values given are the default values assigned by the program. Only values that differ from the defaults actually have to be included in the NAMELIST file.

Note that some compilers do not allow the use of inline descriptive comments (following the !). Some compilers use other formats for the first and last lines of the NAMELIST format file. Check your compiler user's guide for details.

```
$INPUT
  LSTFL   = 'LIST'   ! List file name (CON for console listing)
  OUTFL   = 'OUTPUT' ! Output file name
  MONTH   = 7        ! month of year
  MDAY    = 20       ! day of month
  MYEAR    = 76       ! year (4-digit; 1970-2069 can be 2-digit)
  NPOS     = 21       ! max # positions to evaluate (0 = read data from file)
  IHR      = 12       ! GMT hour of day
  IMIN     = 30       ! minute of hour
  SEC      = 0.0      ! second of minute (for initial position)
  ALSO     = 0.0      ! starting Ls value (degrees) for dust storm (0 = none)
  INTENS   = 0.0      ! dust storm intensity (0.0 - 3.0)
  RADMAX   = 0.0      ! max. radius (km) of dust storm (0 or >10000 = global)
  DUSTLAT  = 0.0      ! latitude (deg) for center of dust storm
  DUSTLON  = 0.0      ! West longitude (deg) for center of dust storm
  F107     = 68.0     ! 10.7 cm solar flux (10**-22 W/cm**2, at 1 AU)
  STDLL    = 0.0      ! std. dev. for thermosphere variation (-3.0 to +3.0)
  MODPERT  = 3        ! perturbation model; 1=random, 2=wave, 3=both
  NR1      = 1001     ! starting random number (0 < NR1 < 30000)
  NVARX    = 1        ! x-code for plotable output (1=hgt above ref. ellipse)
  NVARY    = 0        ! y-code for 2-D plotable output (0 for 1-D plots)
  LOGSCALE = 0        ! 0=regular density, 1=log(density), 2=COSPAR deviations
  FLAT     = 22.0     ! initial latitude (N positive), degrees
  FLON     = 48.0     ! initial longitude (West positive), degrees
  FHGT     = -0.5     ! initial height (km), above ref. ellipse
  DELHGT   = 10.0     ! height increment (km) between steps
  DELLAT   = 0.0      ! latitude increment (deg) between steps
  DELLON   = 0.0      ! West longitude increment (deg) between steps
  DELTIME  = 0.0      ! time increment (sec) between steps
  CF0      = 1.0      ! climate adjustment factor at surface
  CF5      = 1.0      ! climate adjustment factor at 5 km
  CF15     = 1.0      ! climate adjustment factor at 15 km
  CF30     = 1.0      ! climate adjustment factor at 30 km
  CF50     = 1.0      ! climate adjustment factor at 50 km
  CF75     = 1.0      ! climate adjustment factor at 75 km
  deltaZF  = 0.0      ! adjustment for height of 1.26 nbar level (ZF, km)
  deltaTF  = 0.0      ! adjustment for temperature at height ZF (K)
  deltaTEX = 0.0      ! adjustment for exospheric temperature (K)
  Cfp      = 1.0      ! climate adjustment factor for surface pressure
  ipopt    = 1        ! interpolation option 0=regression, 1=hydrostatic
  rpscale  = 1.0      ! scale factor for perturbations (1 = nominal)
  NMONTE   = 1        ! number of Monte Carlo runs to do
  iup      = 1        ! LIST and graphics file output option (0 = none)
                      ! [.ne. 0 means normal output of files (default)]
$END
```

Appendix C

Sample Output LIST File

The following is the LIST file output produced by the standard input parameters as given in Appendix B.

The standard input is also provided to users (along with the program code and other data files) as file "input.std". Output data given here are provided as file "listref3.8". Availability of these files allows users to make a test run after compiling Mars-GRAM on their own machine, and to electronically check their output by a file-compare process (e.g. the "diff" command in UNIX or the "fc" command in DOS). Note that, due to machine-dependent or compiler-dependent rounding differences, some output values may differ slightly from those shown here. These differences are usually no more than one unit in the last significant digit displayed. As shown here, the listing gives numbers in the DOS convention of not displaying zero-valued leading digits before the decimal place. Leading zeroes are given in the UNIX version of listref3.8 provided. If necessary for performing the output test, changes from UNIX format to DOS format can be accomplished with an editing program (e.g. changing all character strings "_0." to "___." and changing all "-0." to "_ -.", where "_" indicates a blank space)

```
Mars-GRAM version 3.8 - February, 1998
Date = 7/20/1976 Julian Date = 2442980.0 GMT Time = 12:30: .0
Height of 1.26 nbar level from hydrostatic interpolation
CF0,CF5,CF15,CF30,CF50,CF75= 1.000 1.000 1.000 1.000 1.000 1.000
CFp,deltaZF,deltaTF,deltaTEX= 1.000 .0 .0 .0
F10.7 flux = 68.0 (1 AU) 25.0 (Mars), standard deviation = .0
Perturbation model = 3 Random seed = 1001 Scale factor = 1.0
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = -1.54 km ( .00 km) Scale Hgt H(p) = 12.74 H(rho) = 14.29 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 247.6 K Pressure = 8.233E+02 N/m**2
Density (Low, Avg., High) = 1.599E-02 1.739E-02 1.880E-02 kg/m**3
Departure, COSPAR NH Mean = -10.7 % -2.8 % 5.0 %
Total Density = 1.886E-02 kg/m**3 Density Perturbation = 8.42 % of mean
Eastward Wind (Mean, Perturbed, Total) = 1.6 -1.5 .1 m/s
Northward Wind (Mean, Perturbed, Total) = -.1 .9 .8 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 8.46 km ( 10.00 km) Scale Hgt H(p) = 10.61 H(rho) = 11.89 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Temperature = 206.1 K Pressure = 3.425E+02 N/m**2
Density (Low, Avg., High) = 8.310E-03 8.691E-03 9.072E-03 kg/m**3
Departure, COSPAR NH Mean = 12.8 % 18.0 % 23.2 %
Total Density = 8.653E-03 kg/m**3 Density Perturbation = -.43 % of mean
Eastward Wind (Mean, Perturbed, Total) = 4.7 -7.9 -3.2 m/s
Northward Wind (Mean, Perturbed, Total) = -5.1 2.8 -2.3 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 18.46 km ( 20.00 km) Scale Hgt H(p) = 9.68 H(rho) = 10.57 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
```

Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Temperature = 188.0 K Pressure = 1.283E+02 N/m**2
 Density (Low, Avg., High) = 3.395E-03 3.568E-03 3.742E-03 kg/m**3
 Departure, COSPAR NH Mean = 11.7 % 17.5 % 23.2 %
 Total Density = 3.479E-03 kg/m**3 Density Perturbation = -2.51 % of mean
 Eastward Wind (Mean, Perturbed, Total) = 1.7 -10.5 -8.8 m/s
 Northward Wind (Mean, Perturbed, Total) = -8.5 -2.7 -11.2 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 28.46 km (30.00 km) Scale Hgt H(p) = 8.89 H(rho) = 9.71 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Temperature = 172.7 K Pressure = 4.431E+01 N/m**2
 Density (Low, Avg., High) = 1.242E-03 1.342E-03 1.442E-03 kg/m**3
 Departure, COSPAR NH Mean = 8.1 % 16.9 % 25.6 %
 Total Density = 1.533E-03 kg/m**3 Density Perturbation = 14.26 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -1.4 -21.4 -22.7 m/s
 Northward Wind (Mean, Perturbed, Total) = -13.2 1.0 -12.2 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 38.46 km (40.00 km) Scale Hgt H(p) = 8.21 H(rho) = 8.75 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Temperature = 159.6 K Pressure = 1.407E+01 N/m**2
 Density (Low, Avg., High) = 4.272E-04 4.612E-04 4.951E-04 kg/m**3
 Departure, COSPAR NH Mean = 6.2 % 14.7 % 23.1 %
 Total Density = 4.837E-04 kg/m**3 Density Perturbation = 4.89 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -5.1 4.1 -1.0 m/s
 Northward Wind (Mean, Perturbed, Total) = -19.2 -17.3 -36.5 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 48.46 km (50.00 km) Scale Hgt H(p) = 7.54 H(rho) = 8.04 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Temperature = 146.5 K Pressure = 4.079E+00 N/m**2
 Density (Low, Avg., High) = 1.291E-04 1.456E-04 1.621E-04 kg/m**3
 Departure, COSPAR NH Mean = -.6 % 12.1 % 24.8 %
 Total Density = 1.543E-04 kg/m**3 Density Perturbation = 5.99 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -9.2 -1.0 -10.2 m/s
 Northward Wind (Mean, Perturbed, Total) = -25.7 -.4 -26.1 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 58.46 km (60.00 km) Scale Hgt H(p) = 7.23 H(rho) = 7.40 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Temperature = 140.5 K Pressure = 1.096E+00 N/m**2
 Density (Low, Avg., High) = 3.402E-05 4.079E-05 4.756E-05 kg/m**3
 Departure, COSPAR NH Mean = -11.9 % 5.6 % 23.1 %
 Total Density = 3.864E-05 kg/m**3 Density Perturbation = -5.27 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -14.1 6.2 -7.9 m/s
 Northward Wind (Mean, Perturbed, Total) = -33.3 21.7 -11.6 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 68.46 km (70.00 km) Scale Hgt H(p) = 6.95 H(rho) = 7.12 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Temperature = 135.1 K Pressure = 2.817E-01 N/m**2
 Density (Low, Avg., High) = 8.988E-06 1.091E-05 1.283E-05 kg/m**3
 Departure, COSPAR NH Mean = -16.1 % 1.8 % 19.7 %
 Total Density = 1.005E-05 kg/m**3 Density Perturbation = -7.90 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -19.3 14.3 -5.0 m/s
 Northward Wind (Mean, Perturbed, Total) = -39.8 43.9 4.2 m/s

Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
Height = 78.46 km (80.00 km) Scale Hgt H(p) = 7.05 H(rho) = 7.14 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
Solar Zenith Angle = 55.2 deg F1 peak = 126.6 km Mol.Wgt. = 43.49
Temperature = 130.8 K Pressure = 6.922E-02 N/m**2
Density (Low, Avg., High) = 2.253E-06 2.768E-06 3.283E-06 kg/m**3
Departure, COSPAR NH Mean = -19.9 % -1.6 % 16.7 %
Total Density = 3.364E-06 kg/m**3 Density Perturbation = 21.51 % of mean
Eastward Wind (Mean, Perturbed, Total) = -25.5 19.4 -6.1 m/s
Northward Wind (Mean, Perturbed, Total) = -45.5 15.9 -29.6 m/s

Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
Height = 88.46 km (90.00 km) Scale Hgt H(p) = 6.97 H(rho) = 7.06 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
Solar Zenith Angle = 55.2 deg F1 peak = 126.6 km Mol.Wgt. = 43.49
Temperature = 128.6 K Pressure = 1.663E-02 N/m**2
Density (Low, Avg., High) = 5.351E-07 6.763E-07 8.174E-07 kg/m**3
Departure, COSPAR NH Mean = -27.5 % -8.4 % 10.7 %
Total Density = 6.826E-07 kg/m**3 Density Perturbation = .94 % of mean
Eastward Wind (Mean, Perturbed, Total) = -39.1 12.6 -26.4 m/s
Northward Wind (Mean, Perturbed, Total) = -52.2 -16.7 -69.0 m/s

Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
Height = 98.46 km (100.00 km) Scale Hgt H(p) = 6.90 H(rho) = 6.98 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
Solar Zenith Angle = 55.2 deg F1 peak = 126.5 km Mol.Wgt. = 43.49
Temperature = 126.5 K Pressure = 3.934E-03 N/m**2
Density (Low, Avg., High) = 1.247E-07 1.627E-07 2.007E-07 kg/m**3
Departure, COSPAR NH Mean = -36.3 % -16.8 % 2.6 %
Total Density = 1.529E-07 kg/m**3 Density Perturbation = -6.02 % of mean
Eastward Wind (Mean, Perturbed, Total) = -62.9 -10.3 -73.2 m/s
Northward Wind (Mean, Perturbed, Total) = -60.1 -44.3 -104.4 m/s

Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
Height = 108.46 km (110.00 km) Scale Hgt H(p) = 7.02 H(rho) = 6.96 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
Solar Zenith Angle = 55.2 deg F1 peak = 126.6 km Mol.Wgt. = 43.27
Temperature = 127.3 K Pressure = 9.345E-04 N/m**2
Density (Low, Avg., High) = 2.913E-08 3.820E-08 4.728E-08 kg/m**3
Departure, COSPAR NH Mean = -42.5 % -24.6 % -6.7 %
Total Density = 2.961E-08 kg/m**3 Density Perturbation = -22.50 % of mean
Eastward Wind (Mean, Perturbed, Total) = -104.2 45.9 -58.2 m/s
Northward Wind (Mean, Perturbed, Total) = -71.7 -37.5 -109.2 m/s

Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
Height = 118.46 km (120.00 km) Scale Hgt H(p) = 7.14 H(rho) = 7.08 km
Latitude = 22.480 degrees West Longitude = 47.970 degrees
Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
Solar Zenith Angle = 55.2 deg F1 peak = 126.7 km Mol.Wgt. = 43.05
Temperature = 128.2 K Pressure = 2.277E-04 N/m**2
Density (Low, Avg., High) = 6.929E-09 9.197E-09 1.147E-08 kg/m**3
Departure, COSPAR NH Mean = -51.9 % -36.1 % -20.3 %

Total Density = 9.490E-09 kg/m**3 Density Perturbation = 3.18 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -121.3 .0 -121.3 m/s
 Northward Wind (Mean, Perturbed, Total) = -89.6 -2.6 -92.2 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 128.46 km (130.00 km) Scale Hgt H(p) = 9.25 H(rho) = 7.28 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 127.9 km Mol.Wgt. = 42.60
 Temperature = 163.4 K Pressure = 6.267E-05 N/m**2
 Density (Low, Avg., High) = 1.499E-09 1.966E-09 2.433E-09 kg/m**3
 Departure, COSPAR NH Mean = -66.4 % -55.9 % -45.5 %
 Total Density = 2.429E-09 kg/m**3 Density Perturbation = 23.57 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -139.4 .8 -138.5 m/s
 Northward Wind (Mean, Perturbed, Total) = -114.1 19.6 -94.5 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 138.46 km (140.00 km) Scale Hgt H(p) = 11.16 H(rho) = 9.92 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 128.9 km Mol.Wgt. = 41.85
 Temperature = 192.5 K Pressure = 2.372E-05 N/m**2
 Density (Low, Avg., High) = 4.731E-10 6.205E-10 7.679E-10 kg/m**3
 Departure, COSPAR NH Mean = -63.2 % -51.7 % -40.2 %
 Total Density = 5.363E-10 kg/m**3 Density Perturbation = -13.57 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -153.8 7.2 -146.7 m/s
 Northward Wind (Mean, Perturbed, Total) = -153.8 .0 -153.8 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 148.46 km (150.00 km) Scale Hgt H(p) = 12.18 H(rho) = 11.31 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 129.5 km Mol.Wgt. = 40.85
 Temperature = 203.8 K Pressure = 1.009E-05 N/m**2
 Density (Low, Avg., High) = 1.855E-10 2.433E-10 3.011E-10 kg/m**3
 Departure, COSPAR NH Mean = -65.2 % -54.4 % -43.6 %
 Total Density = 2.881E-10 kg/m**3 Density Perturbation = 18.44 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -159.4 .0 -159.4 m/s
 Northward Wind (Mean, Perturbed, Total) = -159.4 20.4 -139.0 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 158.46 km (160.00 km) Scale Hgt H(p) = 12.95 H(rho) = 12.10 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 129.9 km Mol.Wgt. = 39.46
 Temperature = 208.2 K Pressure = 4.550E-06 N/m**2
 Density (Low, Avg., High) = 7.445E-11 1.038E-10 1.345E-10 kg/m**3
 Departure, COSPAR NH Mean = -72.3 % -61.3 % -49.9 %
 Total Density = 9.328E-11 kg/m**3 Density Perturbation = -10.10 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -91.4 -23.8 -115.3 m/s
 Northward Wind (Mean, Perturbed, Total) = -161.5 .0 -161.5 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 168.46 km (170.00 km) Scale Hgt H(p) = 13.78 H(rho) = 12.70 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 130.4 km Mol.Wgt. = 37.61

Temperature = 209.9 K Pressure = 2.150E-06 N/m**2
 Density (Low, Avg., High) = 2.998E-11 4.635E-11 6.496E-11 kg/m**3
 Departure, COSPAR NH Mean = -79.7 % -68.6 % -56.0 %
 Total Density = 3.196E-11 kg/m**3 Density Perturbation = -31.03 % of mean
 Eastward Wind (Mean, Perturbed, Total) = -21.5 -61.3 -82.9 m/s
 Northward Wind (Mean, Perturbed, Total) = -158.8 24.3 -134.5 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 178.46 km (180.00 km) Scale Hgt H(p) = 14.83 H(rho) = 13.32 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 131.0 km Mol.Wgt. = 35.26
 Temperature = 210.6 K Pressure = 1.066E-06 N/m**2
 Density (Low, Avg., High) = 1.264E-11 2.148E-11 3.088E-11 kg/m**3
 Departure, COSPAR NH Mean = -85.3 % -74.9 % -64.0 %
 Total Density = 2.826E-11 kg/m**3 Density Perturbation = 31.56 % of mean
 Eastward Wind (Mean, Perturbed, Total) = 18.0 -37.6 -19.6 m/s
 Northward Wind (Mean, Perturbed, Total) = -108.5 -54.2 -162.7 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 188.46 km (190.00 km) Scale Hgt H(p) = 16.21 H(rho) = 14.11 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 131.7 km Mol.Wgt. = 32.48
 Temperature = 210.9 K Pressure = 5.586E-07 N/m**2
 Density (Low, Avg., High) = 5.823E-12 1.035E-11 1.488E-11 kg/m**3
 Departure, COSPAR NH Mean = -88.6 % -79.8 % -71.0 %
 Total Density = 1.180E-11 kg/m**3 Density Perturbation = 13.97 % of mean
 Eastward Wind (Mean, Perturbed, Total) = 29.1 23.6 52.6 m/s
 Northward Wind (Mean, Perturbed, Total) = -66.7 49.6 -17.1 m/s

 Time (rel. to T0) = .0 sec. (.000 sols) Ls = 97.0 deg.
 Height = 198.46 km (200.00 km) Scale Hgt H(p) = 17.98 H(rho) = 15.15 km
 Latitude = 22.480 degrees West Longitude = 47.970 degrees
 Sun Latitude = 25.00 deg. Mars Orbital Radius = 1.649 AU
 Sun Longitude = 108.77 deg. Local Time = 16.05 Mars hours
 Exospheric Temp. = 211.1 K Tbase = 128.6 K Zbase = 122.7 km
 Solar Zenith Angle = 55.2 deg F1 peak = 132.7 km Mol.Wgt. = 29.46
 Temperature = 211.0 K Pressure = 3.105E-07 N/m**2
 Density (Low, Avg., High) = 2.935E-12 5.218E-12 7.501E-12 kg/m**3
 Departure, COSPAR NH Mean = -90.7 % -83.4 % -76.2 %
 Total Density = 5.218E-13 kg/m**3 Density Perturbation = -90.00 % of mean
 Eastward Wind (Mean, Perturbed, Total) = 25.6 -23.7 1.9 m/s
 Northward Wind (Mean, Perturbed, Total) = -40.5 60.9 20.4 m/s

Appendix D

Summary of Files Provided with Mars-GRAM Version 3.8

Provided to the user of Mars-GRAM program and data files are the following:

marsgram.lst - the history file summarizing various versions and changes
marsgram.f - source code for the "stand alone" version main program
dummytraj.f - source code for the dummy trajectory version main program
marssubs.f - subroutines used by both marsgram and dummytraj versions
setup.f - setup subroutines used by both marsgram and dummytraj versions
ARCHGTS.DAT - data file for low resolution Ames MGCM topographic heights
COSPAR.DAT - data file for the COSPAR reference model atmosphere
INPUT.REF - commented test input file for reference case (see Appendix B)
INPUT.STD - non-commented test input file for reference case
listref3.8 - test list output file for the reference case (see Appendix C)
headers.txt - list of plotable output files and file header definitions (see Appendix A)
README.txt - this general program introduction file
README2.txt - discussion of the dummytraj.f dummy trajectory program
bldmgt.f - auxiliary program to build trajectory file with variable CFs
rdmgt.f - auxiliary program to read trajectory file & add variable CFs

Version 3.8 now includes the capability for time- or latitude-dependent climate factors (CFs) on trajectory input data and in the trajectory version. CFs include (CF0, CF5, CF15, CF30, CF50, CF75, CFp, deltaZF, deltaTF, and deltaTEX). To use CFs from the INPUT file, use CFs of 0.0 on the trajectory input file. Non-zero CFs on the trajectory input file or from a trajectory main program will supersede those on the INPUT file. Two auxiliary programs are provided for adding CFs to trajectory files: Program bldmgt.f will generate a "trajectory" consisting of user-defined steps in height, latitude, longitude, and time. Program rdmgt.f will read a previously generated trajectory data file (TRAJDATA, containing time, height, latitude, and longitude) and will add CFs. Both bldmgt and rdmgt programs interpolate CFs from an auxiliary CF data file (cinfo.txt, see description in bldmgt.f or rdmgt.f source code).

NOTE: BEGINNING WITH VERSION 3.6, NO INTERACTIVE VERSION IS INCLUDED.

Plotable output files can be generated with data given versus several selected parameters. Generation of LIST file output and plotable output files is now controlled by value of iup on input. For version 3.8, a reduced number of plotable output files are generated, each containing several parameters suitable for plotting. These new plotable files have headers to help identify parameters in the files. File names and definitions of headers are given in the file headers.txt (Appendix A).

Appendix E

Example Application of Mars-GRAM in a Trajectory Code

With earlier versions of Mars-GRAM a dummy trajectory program, `marstraj.f`, was supplied. With version 3.8 an alternate version of (double precision) dummy trajectory calculating program (`dumytraj.f`) is included. Although similar in general function to the original `marstraj.f` code, the following details of `dumytraj.f` are different, i.e.,

- (1) In `marstraj.f`, interaction with Mars-GRAM was via calls to three subroutines -

```
Call Setup(...)
Call Randinit(...)
Call Datastep(...)
```

These three subroutines are part of the Mars-GRAM code and are automatically available to be called whenever the Mars-GRAM code (`marssubs.f` and `setup.f`) is linked to the user's main trajectory driver program. If you already have a trajectory program built like this, with calls to Setup, Randinit, and Datastep it might be easily modified to incorporate version 3.8 subroutines without using the approach taken in `dumytraj.f`.

- (2) In `dumytraj.f`, interaction with Mars-GRAM is via three calls to one subroutine (named `Marstraj`), but with different values of three control parameters (`isetup`, `jmonte`, and `istep`) -

```
Call Marstraj(...)   with isetup=1
Call Marstraj(...)   with isetup=0, jmonte>0, istep=0
Call Marstraj(...)   with isetup=0, jmonte=0, istep>0
```

where `isetup = 1` triggers the call to the Setup subroutine, `jmonte>0` triggers the call to the reinitialization process (including the call to the Randinit subroutine), and `istep = 1` to MAXNUM is a counter for steps along the trajectory (with a call to the Datastep subroutine at each step). `Marstraj` is a new subroutine that must be included (along with the basic Mars-GRAM code) as a subroutine in the user's calling trajectory program.

- (3) In the original `marstraj.f` dummy trajectory main code, transfer of double precision (trajectory) variables to and from single precision (Mars-GRAM) variables was assumed to be done within the user's main trajectory code. In the `dumytraj.f` code this transfer is handled within the `Marstraj` subroutine (which must be included as a subroutine in the user's trajectory program).

- (4) In the original `marstraj.f`, (single precision) position increments (`DELHGT`, `DELLAT`, and `DELLON`) were presumed to be calculated within the user's main trajectory program. In the `dumytraj.f` code, input variables to the `Marstraj` subroutine are

current and next (double precision) position values (height, latitude, and longitude) and the position increments to be passed to the Datastep subroutine are computed within the Marstraj subroutine.

Regardless of which dummy trajectory code you decide to use as your starting model from which to build the interface to Mars-GRAM for your own trajectory code, it is worthwhile to read the comments embedded in the code for the dummytraj.f version. These comments give more explicit descriptions of the functions that are being performed. They also provide better hints about what to do if you are using predictor-corrector (or other) trajectory approaches that require mid-point corrections along trajectory steps and/or the use of density variations that occur within each trajectory step.

Two new features of dummytraj.f are

- (1) allows high precision Mars ephemeris values for sun latitude and longitude and Ls angle to be passed from the trajectory program for use by Mars-GRAM subroutines and
- (2) allows variable climate factors to be evaluated within the calling trajectory program and passed to Mars-GRAM subroutines for use. Interpolation of climate factors, as necessary, is done by the cfinterp subroutine, supplied as part of the dummytraj.f code.

Appendix F

Summary of Changes in Mars-GRAM Versions 3.5, 3.6, and 3.7

Mars-GRAM Version 3.5 (July, 1996)

- changed temperature renormalization to be at 25 km above reference ellipsoid datum, not 25 km above local terrain height
- removed terms producing large gradient in surface pressure poleward of 55 deg
- added option (ipopt) to do hydrostatic interpolation from 75 km to 1.26 nbar
- added climate adjustment factor for surface pressure (CFp)
- added calculation of density scale height [H(rho), retaining pressure scale height H(p)]
- added plot output files for density scale height [file=HGTrho, unit=35, files(18)], temperature of 1.26 nbar level [file=Tbase, unit=36, files(19)], and height of 1.26 nbar level [file=Zbase, unit=37, files(20)]
- added option for plot output versus pressure level (NVARX or NVARY = 9)
- increased minimum and maximum allowed random perturbation magnitudes (by about a factor of 2), and added input of random perturbation scale factor (rpscale) with allowable values 0-3
- changed lapse rates 30-50 km and 50-75 km (to 1.19 K/km and 0.44 K/km, respectively)
- corrected problem with computing position displacements (DELHGT, DELLAT and DELLON) in mode when trajectory file (TRAJDATA) is read in

Mars-GRAM Version 3.6 (November, 1996)

- added Monte Carlo feature in Batch version and created new dummy trajectory-computing version (marstraj)

- optional NAMELIST format INPUT now includes NMONTE = number on Monte Carlo runs and iup [0 to suppress LIST and graphics output files; iup not equal to zero causes output of LIST and graphics files (default)]
- added random seed (NR1) and NMONTE to argument list of SETUP subroutine
- rewind trajectory input data file (TRAJDATA) when end-of-file is encountered
- apply random perturbation scaling factor (rpscale) to SIGD, DENSII, and DENSLO
- include new subroutine Randinit to re-initialize the random number seed (NR1) for each Monte Carlo run
- NOTE: NO INTERACTIVE VERSION 3.6 IS PROVIDED. Batch (and dummy trajectory) version 3.6 and interactive version 3.5 should give the same output if identical input parameters are used [including NMONTE=1 (the default case)].

Mars-GRAM Version 3.7 (June, 1997)

- added time- or latitude-dependent climate factors (CFs) on trajectory input data CFs include (CF0, CF5, CF15, CF30, CF50, CF75, CFp, deltaZF, deltaTF, and deltaTEX). To use CFs from the INPUT file, use CFs of 0.0 on the trajectory input file. Non-zero CFs on the trajectory input file will supersede those on the INPUT file
- two auxiliary programs are provided for adding CFs to trajectory files, i.e., program bldmgt.f generates a "trajectory" consisting of user-defined steps in height, latitude, longitude, and time and program rdmgt.f reads a previously-generated trajectory data file (TRAJDATA, containing time, height, latitude, and longitude) and will add CFs. Both bldmgt and rdmgt programs interpolate CFs from an auxiliary CF data file (cfinfo.txt, see description in bldmgt.f or rdmgt.f source code)

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13. ABSTRACT (Maximum 200 words) Mars Global Reference Atmospheric Model (Mars-GRAM) Version 3.8 is presented and its new features are discussed. Mars-GRAM uses new values of planetary reference ellipsoid radii, gravity term, and rotation rate (consistent with current JPL values) and includes centrifugal effects on gravity. The model now uses NASA Ames Global Circulation Model low resolution topography. Curvature corrections are applied to winds and limits based on speed of sound are applied. Altitude of the F1 ionization peak and density scale height, including effects of change of molecular weight with altitude are computed. A check is performed to disallow temperatures below CO ₂ sublimation. This memorandum includes instructions on obtaining Mars-GRAM source code and data files and running the program. Sample input and output are provided. An example of incorporating Mars-GRAM as an atmospheric subroutine in a trajectory code is also given.				
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